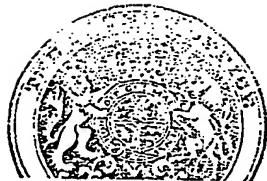


PATENT SPECIFICATION

DRAWINGS ATTACHED

Inventor: ARNOLD WILLIAM MORLEY



366,162

Date of filing Complete Specification March 10, 1960.

Application Date March 10, 1959.

No. 8237,59.

Complete Specification Published Oct. 17, 1962.

ERRATUM

SPECIFICATION NO. 908,443

Page 1, in the heading, for "CLASS" read "Class 4"

THE PATENT OFFICE,
8th November, 1962.

DS 67854/1(18)/R. 109 200 10/62 PL

10 we pray that it may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to apparatus for controlling the power delivered to a rotor on a helicopter from a power unit.

The blades of a helicopter rotor under flight conditions produce on the rotor head loads which are not uniform throughout each revolution of the rotor but vary cyclically, and these cyclic variations in some cases give rise to torsional vibration in the rotor head which in turn may cause vibration in the blades. Apart from being generally undesirable all such vibrations are a potential cause of wear and tear and possible breakdown, particularly if resonance occurs, while they may also be a serious factor in limiting the forward speed of the helicopter.

Such vibrations can be relieved by the use of damping devices but this expedient adds undesirably to the weight of the unit, and it is an object of the present invention to provide other means for reducing or eliminating such vibrations.

Apparatus for controlling the power delivered to a rotor on a helicopter from a power unit according to the present invention comprises a device arranged to operate synchronously with the rotor and controlling power control means to vary the power delivered to the rotor cyclically during each revolution thereof to reduce unwanted vibrations therein.

In the case where a rotor is driven by one or more propulsion jets, situated for example near the tips of the blades and

control the flow of that fluid to the jets cyclically in the required manner. Where, on the other hand, a rotor is driven either by torque applied to the rotor head through transmission mechanism from a power unit, or by one or more jet propulsion or like power units carried by the rotor blades, the synchronous device may be arranged to vary the power output of the power unit or power units cyclically in the required manner.

Preferably the curve representing the cyclic variations from the mean power applied to the rotor conforms approximately with the form of the curve representing the cyclic variations from the mean load on the rotor head caused by the rotor blades.

The synchronous control device may conveniently act on the normal power control equipment of the power unit to cause the appropriate cyclic variations in the power delivered to the rotor, and preferably acts to impose variations on the quantity of fuel delivered to the power unit by the normal fuel control equipment of the power unit.

In arrangements in which the normal mean rate of fuel flow is controlled by a servo device controlled by a main control signal, the control device may act to superimpose cyclic signals on this main control signal.

The cyclic signals are preferably superimposed on the main fuel control signal through apparatus capable of adjustment to vary the characteristics of the signals, for example the amplitude and/or phasing.

In a preferred arrangement means are in-

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PATENT SPECIFICATION

DRAWINGS ATTACHED

Inventor: ARNOLD WILLIAM MORLEY



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Date of filing Complete Specification March 10, 1960.

Application Date March 10, 1959.

No. 8237,59.

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Index at acceptance: 'A9A3(A:B:D), C1G.

International Classification:—B64c, d.

COMPLETE SPECIFICATION

Control Apparatus for the Power Units of Helicopters

We, D. NAPIER & SON LIMITED, a Company registered under the Laws of Great Britain, of 211, Acton Vale, London, W.3, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to apparatus for controlling the power delivered to a rotor on a helicopter from a power unit.

The blades of a helicopter rotor under flight conditions produce on the rotor head loads which are not uniform throughout each revolution of the rotor but vary cyclically, and these cyclic variations in some cases give rise to torsional vibration in the rotor head which in turn may cause vibration in the blades. Apart from being generally undesirable all such vibrations are a potential cause of wear and tear and possible breakdown, particularly if resonance occurs, while they may also be a serious factor in limiting the forward speed of the helicopter.

Such vibrations can be relieved by the use of damping devices but this expedient adds undesirably to the weight of the unit, and it is an object of the present invention to provide other means for reducing or eliminating such vibrations.

Apparatus for controlling the power delivered to a rotor on a helicopter from a power unit according to the present invention comprises a device arranged to operate synchronously with the rotor and controlling power control means to vary the power delivered to the rotor cyclically during each revolution thereof to reduce unwanted vibrations therein.

In the case where a rotor is driven by one or more propulsion jets, situated for example near the tips of the blades and

fed from a source of gaseous working fluid, such as a combustion turbine mounted on the body of the helicopter, the synchronous device could be arranged to control the output of the combustion turbine or other source of gaseous working fluid and/or to control the flow of that fluid to the jets cyclically in the required manner. Where, on the other hand, a rotor is driven either by torque applied to the rotor head through transmission mechanism from a power unit, or by one or more jet propulsion or like power units carried by the rotor blades, the synchronous device may be arranged to vary the power output of the power unit or power units cyclically in the required manner.

Preferably the curve representing the cyclic variations from the mean power applied to the rotor conforms approximately with the form of the curve representing the cyclic variations from the mean load on the rotor head caused by the rotor blades.

The synchronous control device may conveniently act on the normal power control equipment of the power unit to cause the appropriate cyclic variations in the power delivered to the rotor, and preferably acts to impose variations on the quantity of fuel delivered to the power unit by the normal fuel control equipment of the power unit.

In arrangements in which the normal mean rate of fuel flow is controlled by a servo device controlled by a main control signal, the control device may act to superimpose cyclic signals on this main control signal.

The cyclic signals are preferably superimposed on the main fuel control signal through apparatus capable of adjustment to vary the characteristics of the signals, for example the amplitude and/or phasing.

In a preferred arrangement means are in-

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cluded for sensing the amplitude of the cyclic variations from the mean load on the rotor head caused by the cyclic loads on the rotor blades and for adjusting the amplitude of the signals superimposed on the main signal to make them some predetermined value in dependence on the amplitude of the cyclic variations from the mean load on the rotor head.

10 Servo apparatus may thus be included which is responsive both to the blade loads at the rotor head, and to the torque transmitted to the rotor by the power unit, and operating to vary the amplitude of the signals superimposed on the main signal.

15 In the case where a single rotor is arranged to be driven by two or more power units, any one or more of the power units may be controlled in the manner set forth, 20 and in the case where two or more rotors are driven from a single power unit or from two or more power units through interconnected transmission mechanisms the cyclic variations imposed on the mean power output of the power unit or units will conform approximately with a curve derived from a combination of the load variations on the two or more rotors.

25 The frequency of the cyclic variations from the normal power delivered to the rotor by the power turbine of a gas turbine engine to which the invention is applied, will preferably be sufficiently high not materially to affect cyclically the temperature of the turbine blades, while their amplitude will be sufficiently low not to cause any corresponding cyclic operation of the free wheel usually fitted between the power unit and the rotor.

30 Thus, in a preferred arrangement according to the invention as applied to a combustion turbine the mean speed of the combustion turbine is governed and controlled in the normal way and a cyclic pulse is superimposed upon the normal fuel control equipment in such a way as to produce cyclic variations on the normal fuel supply such that the ripple thus superimposed on the line representing the mean torque of the turbine will not affect the normal governing.

35 With the invention it will be apparent that the torque fluctuation in the power unit at any mean power output will be of a frequency much lower than the rotational speed of the engine. Moreover, although such torque fluctuation would impose varying forces on the engine mountings, the normal flexible supports could readily accommodate them.

40 One form which the invention might take is shown diagrammatically in the drawings accompanying the provisional specification, in which:

45 Figure 1 is a diagrammatic side elevation of a power unit driving a helicopter rotor,

Figure 2 shows diagrammatically an arrangement by which pulses can be superimposed upon the fuel supply system of the power unit indicated in Figure 1 to provide a cyclic variation from the normal mean power output of the unit,

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Figure 3 is a curve showing a typical cyclic variation from the normal torque delivered by a power unit by use of the present invention; and also with reference to the drawing accompanying the complete specification, which is a diagrammatic side elevation of the power unit shown in Figure 1 provided with apparatus responsive to the blade loads and the torque delivered by the power unit for adjusting the amplitude of the cyclic pulses applied to the normal fuel system. In this figure like parts are given the same reference numerals as in the previous figures, and such parts will not be described again in detail.

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20 In the arrangement diagrammatically shown in Figure 1 of the drawings accompanying the provisional specification, the rotor head 1 is assumed to have four blades 2 and is driven by a shaft 3 through reduction gearing 4 from a combustion turbine 5 having power control means in the form of a fuel metering unit 6 which may be of normal type apart from modifications indicated diagrammatically in Figure 2 and referred to hereafter.

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25 Driven from the rotor head 1 is a device operated synchronously with the rotor head in the form of a pulse generator 7 arranged to deliver pulses through a pipe indicated at 8 at a rate corresponding to the speed of rotation of the head 1 multiplied by the number of blades (that is to say four) or a multiple of this.

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30 In Figure 2, 9 represents the piston of a fuel pump control servo device of known type which controls the output of the fuel pump in accordance with a fluid pressure signal received from a speed governer unit indicated at 10, all in a manner well known per se. In the arrangement according to the present invention the servo piston 9 carries an extension 11 constituting a subsidiary piston arranged to be subject to the pressure in a chamber 11a. On the mean pressure in the chamber 11a are superimposed a series of pulses derived from the pulse generator 7 so that the rate of fuel supply is varied cyclically from its mean value by the pulses.

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35 The pulse generator may be of the general form indicated in Figure 2, comprising an inlet passage 12 to which fuel is delivered by the fuel pump, a rotary interrupter disc 13 driven from the rotor 1 through a shaft 14 so as to revolve at rotor speed and having four holes 15 therein to correspond to the number of rotor blades, this interrupter disc being arranged to rotate in a

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chamber so that each of the holes 15 in turn forms a communicating passage between the inlet passage 12 and a relief or fluid return passage 16. It will thus be seen that as the interrupter disc 13 rotates communication between the inlet passage 12 and the relief passage 16 is alternately made and interrupted, the periodicity of the interruptions being equal to the speed of rotation of the rotor multiplied by the number of rotor blades. Leading from the inlet passage 12 through a tuner device indicated at 18 to the chamber 11a is the pulse transmitting pipe 8. Thus it will be apparent that each time communication between the inlet passage 12 and the relief passage 16 is interrupted a pressure pulse will be transmitted through the pulse transmitting pipe 8. The tuner device 18 may be in the form of an adjustable restriction in the pipe 8 arranged to control the amplitude and/or other characteristics of the pulses delivered to the chamber 11a for the purpose of producing cyclic variations in the torque delivered by the combustion turbine most nearly consistent with those produced by the cyclic variations in the load on the rotor head caused by the variations in the loads on the blades.

The characteristics of the pulses may also be varied by suitably shaping the holes 15 in the interrupter disc 13, and the phasing of the pulses may be altered by altering the angular position of the disc 13 relative to the shaft 14. The apparatus so far described is not directly sensitive to load variations on the rotor head, but can readily be adjusted, in conjunction for example with a torque meter in the rotor drive, so that unwanted vibrations in the rotor are reduced or substantially eliminated.

In the arrangement shown in the drawing accompanying the present specification rotor load sensing means 20 are included for sensing the amplitude of the cyclic variations from the mean load on the rotor head 1 caused by the cyclic loads on the blades 2.

In practice the instantaneous rotor load depends primarily upon the instantaneous blade pitch, the pitch being altered cyclically as the rotor rotates, as is well known. The rotor load can therefore be sensed indirectly by sensing blade pitch. In this particular arrangement the blade pitch is sensed by a mechanical linkage indicated generally at 20, which is connected to the blade pitch control mechanism (not shown) in the rotor head. The linkage 20 is connected to and arranged to control a variable control orifice 21 arranged in a hydraulic pipe line 22 leading from the fuel metering unit 6 to one side of a servo device 23. Hydraulic fluid (consisting of liquid fuel) from an engine torque meter (not shown)

associated with gearing 4 between the turbine 5 and the rotor shaft 3 is supplied to the other side of the servo device 23 through a passage 24, the pressure being determined according to the torque being supplied by the power unit, and the hydraulic fluid escapes from the servo device through fixed orifices 25 and pipe line 26. The piston 27 and piston rod 28 of the servo device 23 act on the pulse generator 7, and in particular on the tuner device 18 therein to control the amplitude and/or phase of the pulses delivered to the chamber 11a as previously described. It will be seen that the amplitude of the cyclic load variations on the rotor head 1 and the cyclic variations in the torque delivered by the power unit are compared in the servo device and the resultant acts to vary the amplitude of the pulse superimposed on the normal rate of fuel flow by the pulse generator 7, the amplitude of the pulse for a given position of the operative parts of the servo device being some predetermined value. The variation in the pulse will be such as to tend to reduce the difference between the pressures on opposite sides of the servo piston 27, and in effect to match up the engine torque variations with the rotor load variations. In other words the curve representing the cyclic variations from the mean power applied to the rotor will conform approximately with the form of the curve representing the cyclic variations from the mean load on the rotor head caused by the rotor blades. This will result in a reduction in the cyclic vibrations of the rotor or the rotor drive.

It is to be understood that, although in the example of the invention more particularly described above, the pulse generator is of the hydraulic type and the pulses are fed to the servo piston which controls the fuel pump, the required pulses could be transmitted electrically or by a combined electric and hydraulic system or otherwise, and/or could be arranged to provide the required cyclic variation in the fuel supplied to the power unit in other ways, for example by superimposing a small cyclic movement on the main fuel control member or providing for a cyclically varying escape of fuel from or injection of extra fuel into the system, or otherwise.

WHAT WE CLAIM IS:—

1. Apparatus for controlling the power delivered to a rotor on a rotary wing aircraft from a power unit, comprising a device arranged to operate synchronously with the rotor and controlling power control means to vary the power delivered to the rotor cyclically during each revolution thereof to reduce unwanted vibrations therein.

2. Apparatus as claimed in Claim 1 in which the synchronous device and its con-

- nection to the power control means are such that the curve representing the cyclic variations from the mean power applied to the rotor conforms approximately with the form 35
 5 of the curve representing the cyclic variations from the mean load on the rotor head caused by the rotor blades.
3. Apparatus as claimed in Claim 1 or 40
 10 Claim 2 in which the control device acts on the normal power control equipment of the power unit to cause the cyclic variations in the power delivered to the rotor.
4. Apparatus as claimed in Claim 3 in 45
 15 which the control device acts to impose variations on the quantity of fuel delivered to the power unit by the normal fuel control equipment of the power unit.
5. Apparatus as claimed in Claim 4 in 50
 20 which the normal mean rate of fuel flow is controlled by a servo device controlled by a main control signal, and the control device acts to superimpose cyclic signals on this main control signal.
6. Apparatus as claimed in Claim 5 including means for varying the characteristics 55
 25 of the signals, for example the amplitude and/or phasing.
7. Apparatus as claimed in Claim 6 including means for sensing the amplitude of 60
 30 the cyclic variations from the mean load on the rotor head caused by the cyclic loads on the rotor blades and for adjusting the amplitude of the signals superimposed on
- the main signal to make them some predetermined value in dependence on the amplitude 35
 of the cyclic variations from the mean load on the rotor head.
8. Apparatus as claimed in Claim 8 including servo apparatus responsive both to 40
 the blade loads at the rotor head, and to the torque transmitted to the rotor by the power unit, and operating to vary the amplitude of the signals superimposed on the main signal.
9. Apparatus as claimed in any one of 45
 Claims 5, 6, 7 or 8, in which the superimposed signals are transmitted through a hydraulic system.
10. Apparatus as claimed in any one of 50
 Claims 4, 5, 6, 7, 8 or 9 in which the apparatus is applied to a combustion turbine the mean speed of which is governed and controlled in the normal way and a cyclic pulse is superimposed upon the normal fuel control equipment in such a way as to produce cyclic variations on the normal fuel supply such that the ripple thus superimposed on the mean torque of the turbine would not affect the normal governing.
11. Apparatus substantially as specifically 60
 described with reference to the accompanying drawings and the drawing accompanying the provisional specification.

KILBURN & STRODE,
 Agents for the Applicants.

PROVISIONAL SPECIFICATION

Control Apparatus for the Power Units of Helicopters

We, D. NAPIER & SON LIMITED, a Company registered under the Laws of Great Britain, of 211, Acton Vale, London, W.3, do hereby declare this invention to be described in the following statement:—

The invention relates to control apparatus for the power units of helicopters.

The blades of a helicopter rotor under flight conditions produce on the rotor head loads which are not uniform throughout each revolution of the rotor but vary cyclically, and these cyclic variations in some cases give rise to torsional vibration in the rotor head which in turn may cause vibration in the blades. Apart from being generally undesirable all such vibrations are a potential cause of wear and tear and possible breakdown, particularly if resonance occurs, while they may also be a serious factor in limiting the forward speed of the helicopter.

Such vibrations can be relieved by the use of damping devices but this expedient adds undesirably to the weight of the unit, and it is an object of the present invention to provide other means for reducing or eliminating such vibrations.

90 Control apparatus for the power unit or

units which drive a rotor or rotors of a helicopter according to the present invention includes a device (hereinafter for convenience called the pulse transmitting device) arranged to be operated synchronously with the rotor or rotors, and control means operated or controlled by the pulse transmitting device and by which the power transmitted to the rotor or each rotor by the power unit or power units is varied cyclically during each revolution of the rotor in a manner having such relation to the cyclic variations in the loads on the rotor blades as to tend to prevent unwanted vibration of the rotor.

In the case where a rotor is driven by one or more propulsion jets, situated for example near the tips of the blades and fed from a source of gaseous working fluid, such as a combustion turbine mounted on the body of the helicopter, the pulse transmitting device could be arranged to control the output of the combustion turbine or other source of gaseous working fluid and/or to control the flow of that fluid to the jets cyclically in the required manner. Where, on the other hand, a rotor is driven either by torque applied to the rotor head through

transmission mechanism from one or more power units, or by one or more jet propulsion or like power units carried by the rotor blades, the pulse transmitting device may be arranged to vary the power output of the power unit or power units cyclically in the required manner.

In any case it will be appreciated that the required cyclic variation in output, whether of a gas turbine or other source of gaseous working fluid feeding propulsion jets, or of a power unit in the form of a jet propulsion unit or of a power unit arranged to transmit torque to the rotor head, will conveniently be effected by a control of the fuel supply to the turbine or other power unit in such manner as to cause appropriate cyclic variations in the rate of such supply.

Moreover, while in a simple arrangement according to the invention the cyclic variations in the power applied to the rotor or rotors may synchronize with but not conform closely in character to the cyclic variations required to match the loads on the rotor, in other cases the curve representing the cyclic variations in the power applied to the rotor may conform more closely to that representing the cyclic variations in the torque required to drive the rotor at substantially constant speed throughout each revolution.

In the case of a power unit arranged to drive a single rotor of a helicopter, the control apparatus according to the invention would be arranged to superimpose upon the normal control of the power unit a cyclic variation such as to produce the required cyclic variation in the torque applied by the power unit to the rotor, the period of the cyclic variations being that of rotation of the rotor multiplied by the number of blades incorporated in the rotor or some multiple of this.

In the case where a single rotor is arranged to be driven by two or more power units, any one or more of the power units may be controlled in such a way as to superimpose upon the mean power applied to the rotor during each revolution a cyclic variation the periodicity of which is that of the rotation of the rotor multiplied by the number of blades or some multiple of this.

In the case where two rotors are driven from a single power unit or from two or more power units through interconnected transmission mechanisms the cyclic variation imposed upon the mean power output of the engine or engines will be of such periodicity as to tend to maintain both the rotors at substantially constant speed, that is to say will be generally in accordance with a curve derived from a combination of the torque curves of the two rotors. Similarly if a helicopter were provided with three or more

rotors driven from a single power unit or from two or more power units through interconnected transmission mechanism, the curve representing the cyclic variation superimposed upon the mean power output of the engine or engines would follow generally a curve derived from a combination of the three or more torque curves of the three or more rotors.

Where the power unit or each of a number of power units is in the form of a gas turbine the required cyclic variation in power output can be obtained by superimposing upon the mean rate of fuel flow to the engine a suitable cyclic fluctuation since the power output of the turbine will respond rapidly to such fluctuations in the fuel supply. Thus in such a case where, as is usual, the fuel flow is controlled by a servo device, there may be superimposed upon the main control signal by which the mean rate of fuel flow is controlled, appropriate cyclic pulses having a periodicity determined by the speed of rotation of the rotor, to which pulses the fuel control system responds so as to provide the required cyclic changes in the instantaneous torque applied to the rotor by the turbine to maintain the rotor speed substantially constant during the revolution of the rotor. The frequency of the pulses representing rises in the torque delivered by the power turbine above the mean, would be sufficiently high not materially to affect cyclically the temperature of the turbine blades while their amplitude would be sufficiently low not to cause any corresponding cyclic operation of the free wheel usually fitted between the power unit and the rotor.

In one arrangement according to the invention as applied to a combustion turbine the mean speed of the combustion turbine would be governed and controlled in the normal way and a cyclic pulse controlled system would be superimposed upon the main control system in such a way as to produce cyclic variations in the fuel supply such that the ripple thus superimposed on the line representing the mean torque of the turbine would not affect the normal governing. Thus, the pulse signal could be fed into the fuel metering system through apparatus capable of adjustment to vary the phasing and/or amplitude of the pulses, and if desired the characteristics of the pulses, so as to enable adjustments to be made to provide the smoothest obtainable rotation of the rotor in flight.

With the invention it will be apparent that the torque fluctuation in the power unit at any mean power output will be of a frequency much lower than the rotational speed of the engine. Moreover although such torque fluctuation would impose varying forces on the engine mountings, the

normal flexible supports could readily accommodate them.

According to a further feature of the invention the controlled cyclic variations in engine power produced by the present invention may be used to oppose unwanted vibratory forces acting on the rotor head other than the cyclic variations in rotor torque with which the invention is principally designed to deal.

One form which the invention might take is shown diagrammatically in the accompanying drawings, in which:—

Figure 1 is a diagrammatic side elevation

of a power unit driving a helicopter rotor, Figure 2 shows diagrammatically an arrangement by which pulses can be superimposed upon the fuel supply system of the power unit indicated in Figure 1 to provide a cyclic variation in the power output of the unit, and

Figure 3 is a curve showing a typical cyclic variation in the torque delivered by a power unit by use of the present invention.

In the arrangement diagrammatically shown in Figure 1 the rotor head 1 is assumed to have four blades 2 and is driven by a shaft 3 through reduction gearing 4 from a combustion turbine 5 having a fuel metering unit 6 which may be of normal type apart from modifications indicated diagrammatically in Figure 2 and referred to hereafter.

Driven from the rotor head 1 is a pulse generator 7 arranged to deliver pulses through a pipe indicated at 8 at a rate corresponding to the speed of rotation of the head 1 multiplied by the number of blades (that is to say four) or a multiple of this.

In Figure 2, 9 represents the piston of a fuel pump control servo device of known type which controls the output of the fuel pump in accordance with a fluid pressure signal received from a speed governor unit indicated at 10, all in a manner well known per se. In the arrangement according to the present invention the servo piston 9 carries an extension 11 constituting a subsidiary piston arranged to be subject to the pressure in a chamber 11a. On the mean pressure in the chamber 11a are superimposed a series of pulses derived from the pulse generator 7 so that the rate of fuel supply is varied cyclically by the pulses.

The pulse generator may be of the general form indicated in Figure 2, comprising an inlet passage 12 to which fuel is delivered by the fuel pump, a rotary interrupter disc 13 driven from the rotor 1 through a shaft 14 so as to revolve at rotor speed and having four holes 15 therein to correspond to the number of rotor blades, this interrupter disc being arranged to rotate in a chamber so that each of the holes 15 in turn forms a communicating passage between the inlet pas-

sage 12 and a relief or fluid return passage 16. It will thus be seen that as the interrupter disc 13 rotates communication between the inlet passage 12 and the relief passage 16 is alternately made and interrupted, the periodicity of the interruptions being equal to the speed of rotation of the rotor multiplied by the number of rotor blades. Leading from the inlet passage 12 through a tuner device indicated at 18 to the chamber 11a is the pulse transmitting pipe 8. Thus it will be apparent that each time communication between the inlet passage 12 and the relief passage 16 is interrupted a pressure pulse will be transmitted through the pulse transmitting pipe 8. The tuner device 18 may be in the form of an adjustable restriction in the pipe 8 which may be rotatable relative to the interrupter disc to provide a change of phase or may be otherwise arranged to control the amplitude and phase and/or the characteristics of the pulses delivered to the chamber 11a for the purpose of producing cyclic variations in the torque delivered by the combustion turbine most nearly consistent with those required to maintain the instantaneous rotor speed substantially constant during each revolution.

If desired control apparatus according to the invention may include means, separate from or incorporated in the pulse generator, for sensing the amplitude of the cyclic variations in the blade loads at the rotor head and comparing these with the variations in torque delivered by the engine under the control of the control apparatus, and servo apparatus responsive to the instantaneous blade load at the rotor head and the engine torque, arranged to ensure that under all conditions the variations in engine torque produced by the control apparatus corresponded approximately to those required to counteract the variations in the blade loads at the rotor head and thus maintain the rotor at substantially constant speed.

It is to be understood that, although in the example of the invention more particularly described above, the pulse generator is of the hydraulic type and the pulses are fed to the servo piston which controls the fuel pump, the required pulses could be transmitted electrically or by a combined electric and hydraulic system or otherwise, and/or could be arranged to provide the required cyclic variation in the fuel supplied to the power unit in other ways, for example by superimposing a small cyclic movement on the main fuel control member or providing for a cyclically varying escape of fuel from or injection of extra fuel into the system, or otherwise.

Moreover in any event the wave form of the pulses may be determined in accordance with requirements, as for example in the case of hydraulic pulses by suitable

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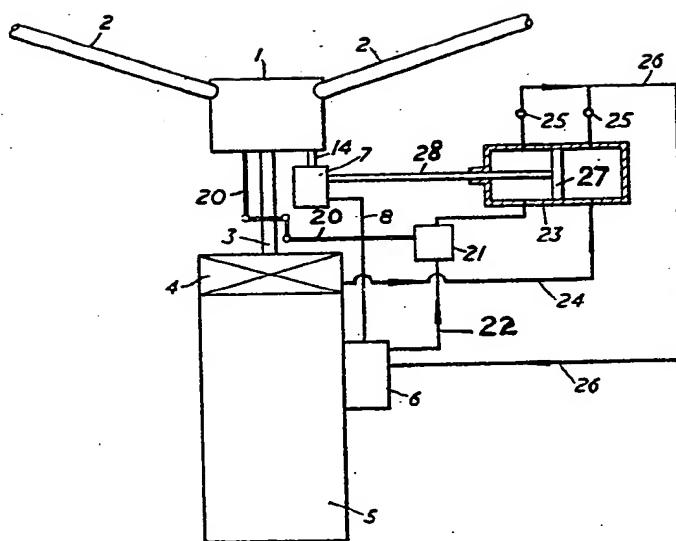
shaping of the ports of the pulse-producing apparatus.

KILBURN & STRODE,
Agents for the Applicants.

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Published at The Patent Office, 25, Southampton Buildings, London, W.C.2, from which copies may be obtained.

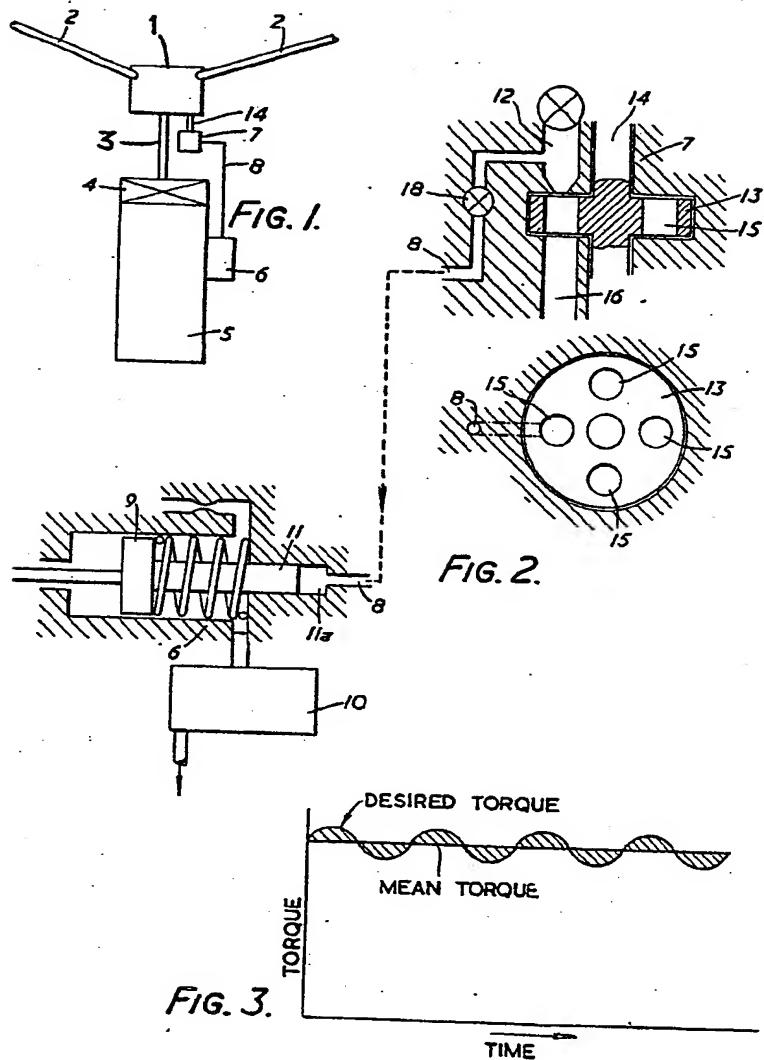
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